
eBeam
Initiative

eBeam Initiative Luncheon

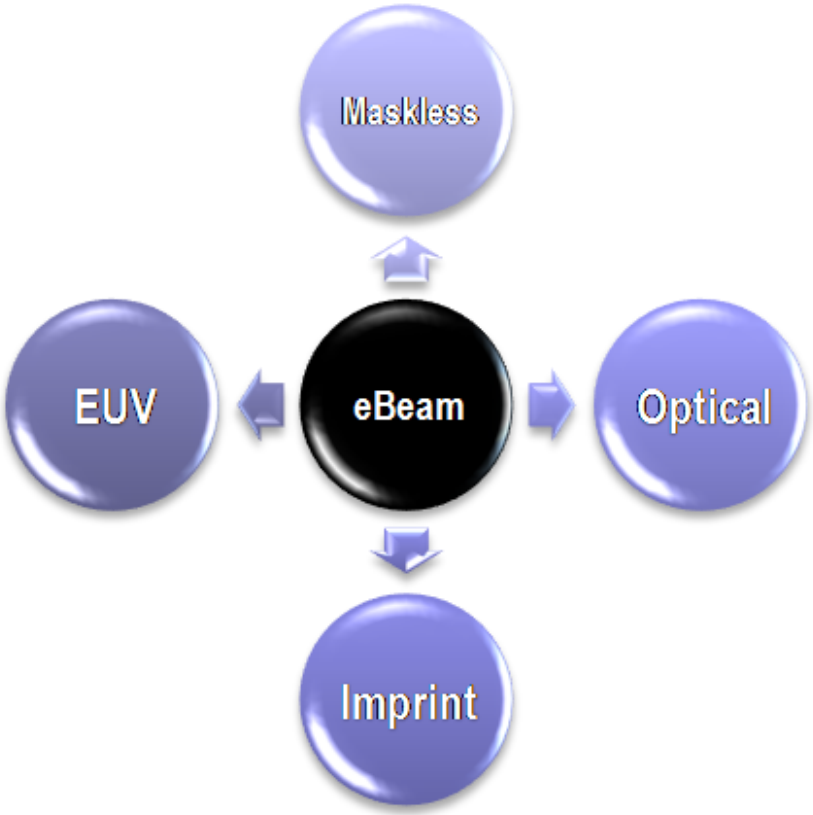
SPIE – February 14, 2012

Aki Fujimura
CEO – D2S, Inc.
Managing Company Sponsor – eBeam Initiative

eBeam Writes All Chips

The eBeam Initiative:

- Is an educational platform for all lithography approaches including Maskless and Imprint
- Open to any company in the semiconductor design chain with an interest in eBeam technologies



42 Member Companies & Advisors

eBeam Initiative

www.ebeam.org

aBeam technologies

ADVANTEST

ADVANCED MASK TECHNOLOGY CENTER

alchip

APPLIED MATERIALS

ARTWORK CONVERSION
CAD Translators
Postprocessors
Plotter Drivers

aselta NANOGRAPHICS

cadence

D2S

DNP Dai Nippon Printing

EQUIcon

eShuttle

FASTRACK DESIGN

eSilicon

Jack Harding
eSilicon

Fraunhofer CNT

FUJITSU

GenISys

GLOBALFOUNDRIES

Grenon Consulting

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ims chips

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KLA-Tencor
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cea leti

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PMC-Sierra

Mentor Graphics

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Qualcomm

PETERSEN ADVANCED LITHOGRAPHY INC.

SAMSUNG

SoftJin
Enabling Electronic Design

SYNOPSYS

Tela Innovations

TOOL

TOPPAN

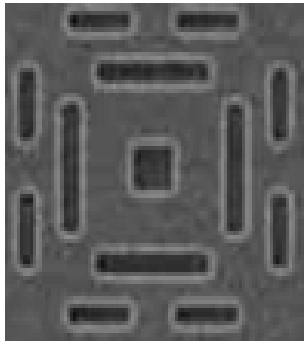
Jean-Pierre Geronimi
ST

Vistec

XILINX

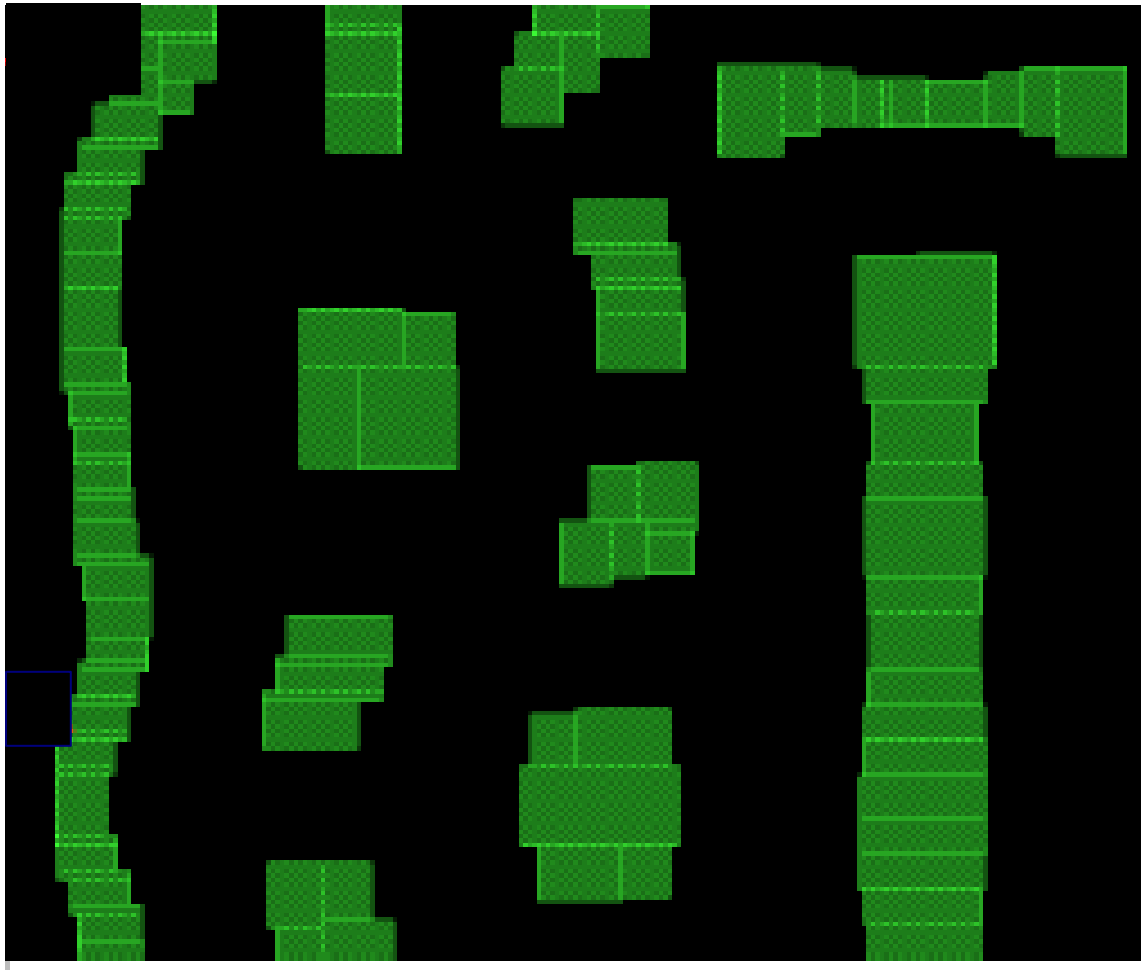
2010 Design for eBeam (DFeB) Roadmap: Complex Mask Shapes are Required at 20 nm & Beyond

28nm



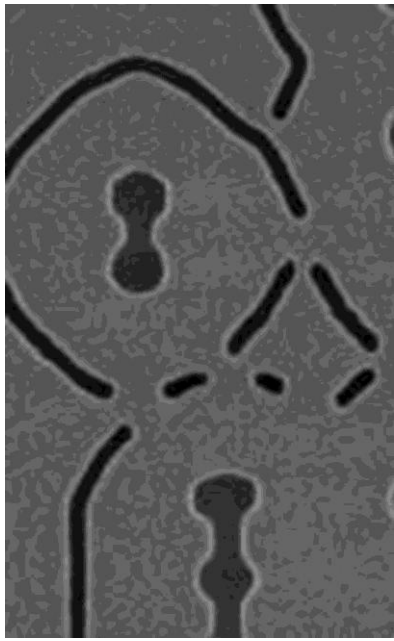
Courtesy : Samsung

20nm



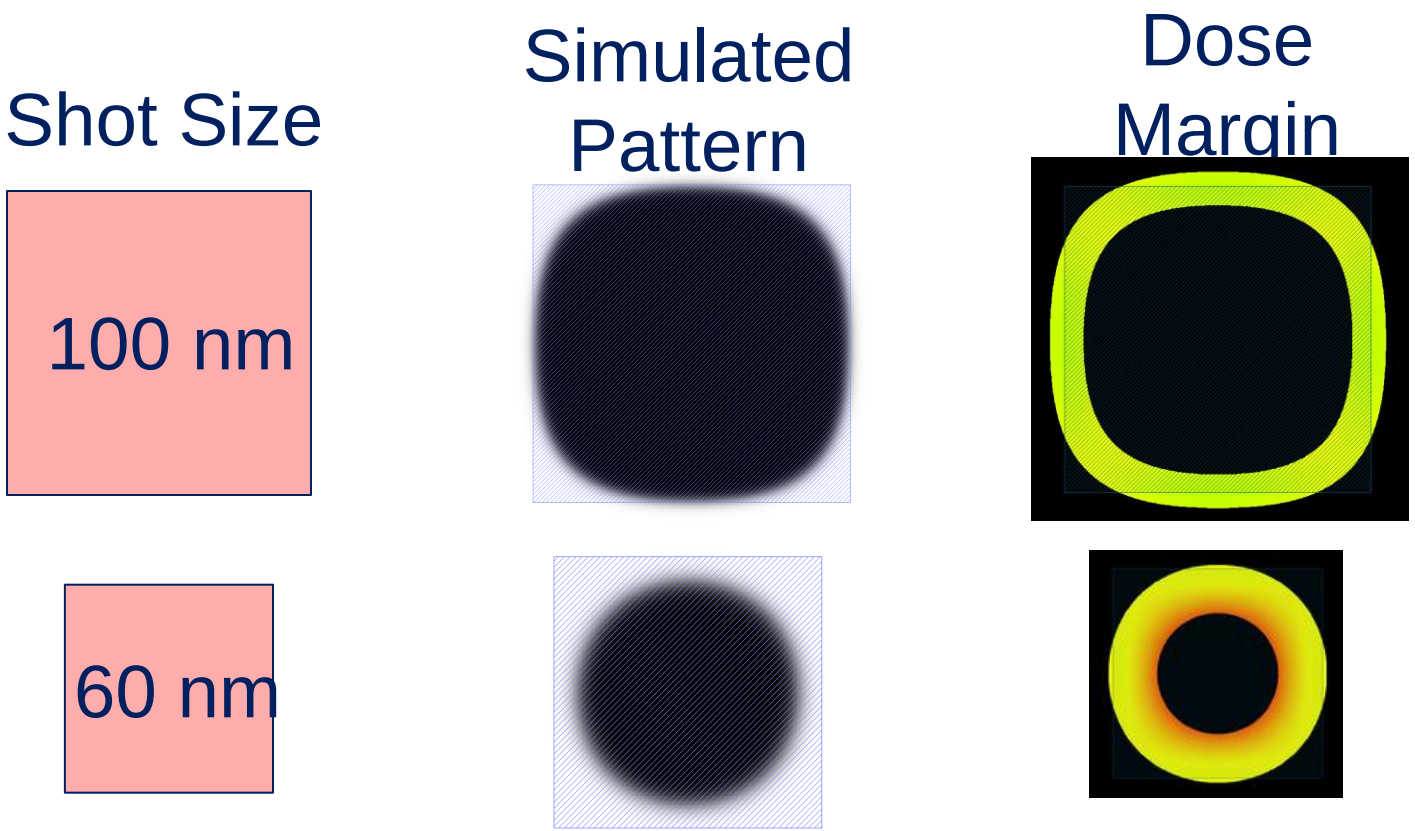
Courtesy : IBM

14nm



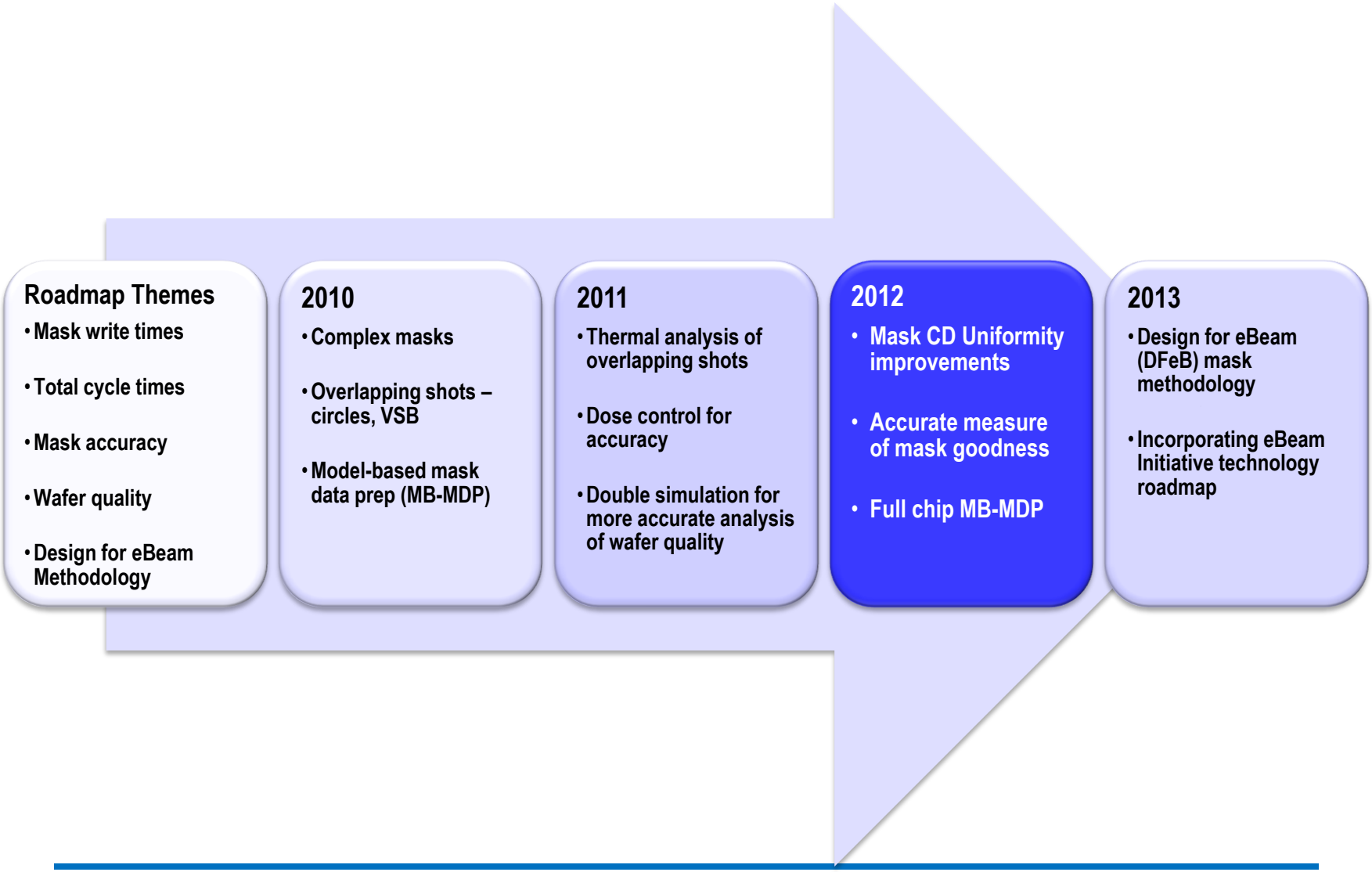
Courtesy : DNP

2011 Design for eBeam (DFeB) Roadmap: Sub-80-nm Discontinuity Has Arrived



The old assumption : Dose Margin is independent of shape
The new world : Dose Margin depends on shape and size

2012 Design for eBeam (DFeB) Roadmap: Importance of Mask CD Uniformity



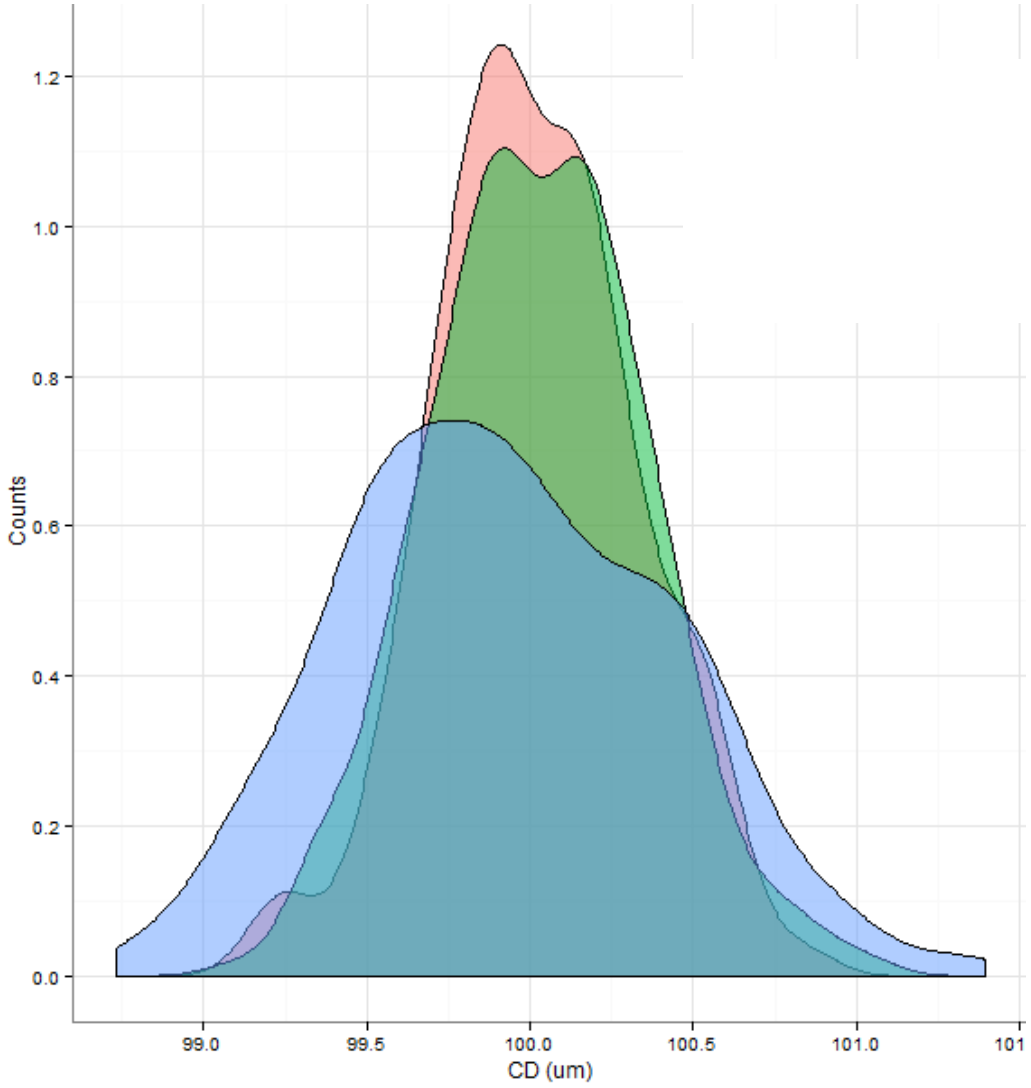
Today's Speakers

- **Insights into Mask CD Uniformity Improvement**
  - Ryan Pearman, Director of Modeling – D2S, Inc.

- **A Scaling Path to 10/11nm using Complementary e-Beam Lithography (CEBL)**
  - Mike Smayling, Sr. VP Product Technology – Tela Innovations, in collaboration with CEA-Leti

- **Q&A**

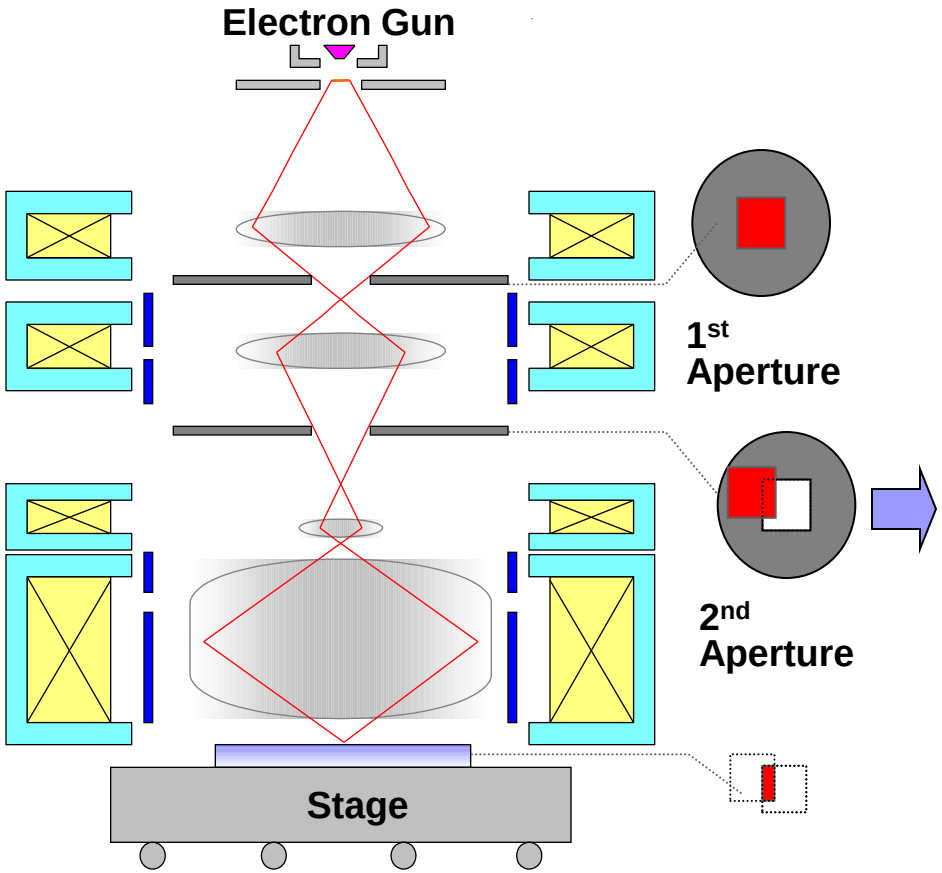
Improving CD Uniformity

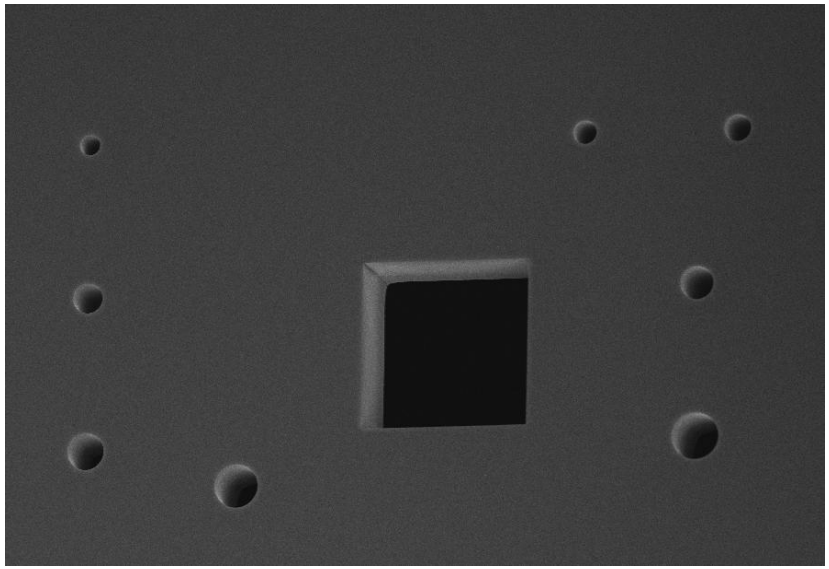


eBeam Technologies to Improve Mask CDU

- **Dose Modulation**
- **Mask Process Correction (MPC)**
- **Model Based - Mask Data Prep (MB-MDP)**
  - Enables overlapping shots, dose modulation and circular (or any shape) shots
- **Circular eBeam Shots**
  - Requires MB-MDP and machine support

Writer Support of Circular Apertures

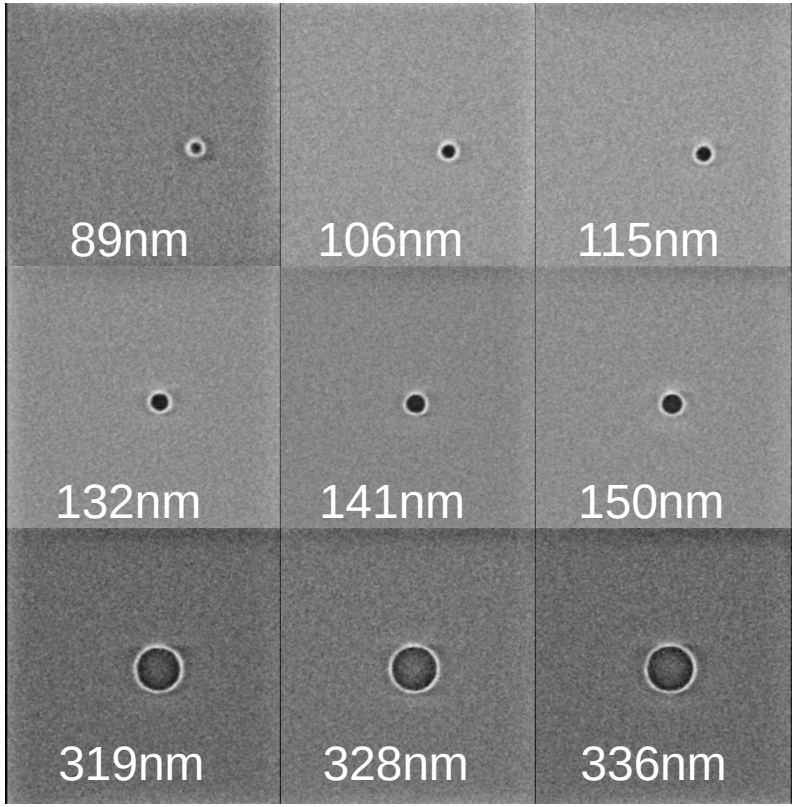




2nd Aperture with circles

Graphics and pictures courtesy JEOL, Ltd.

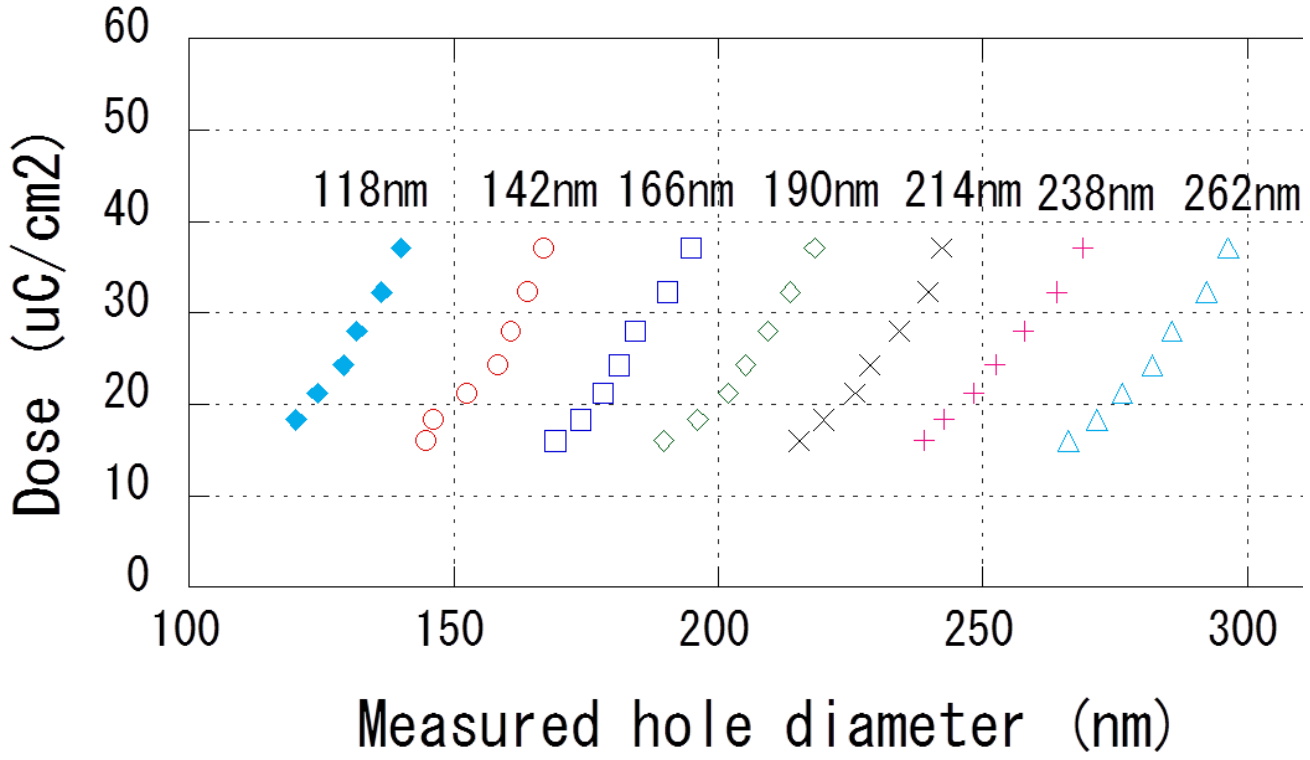
Circles in Addition to Rectangles

Dose provided:	16.0 uC/cm²	19.7 uC/cm²	24.3 uC/cm²
Shot diameter = 118			
Hole Diameter on mask (measured)	89nm	106nm	115nm
Shot Diameter = 142			
Hole Diameter on mask (measured)	132nm	141nm	150nm
Shot Diameter = 334			
Hole Diameter on mask (measured)	319nm	328nm	336nm

Resist : FEP171 (300nm)

Graphics and pictures courtesy JEOL, Ltd.

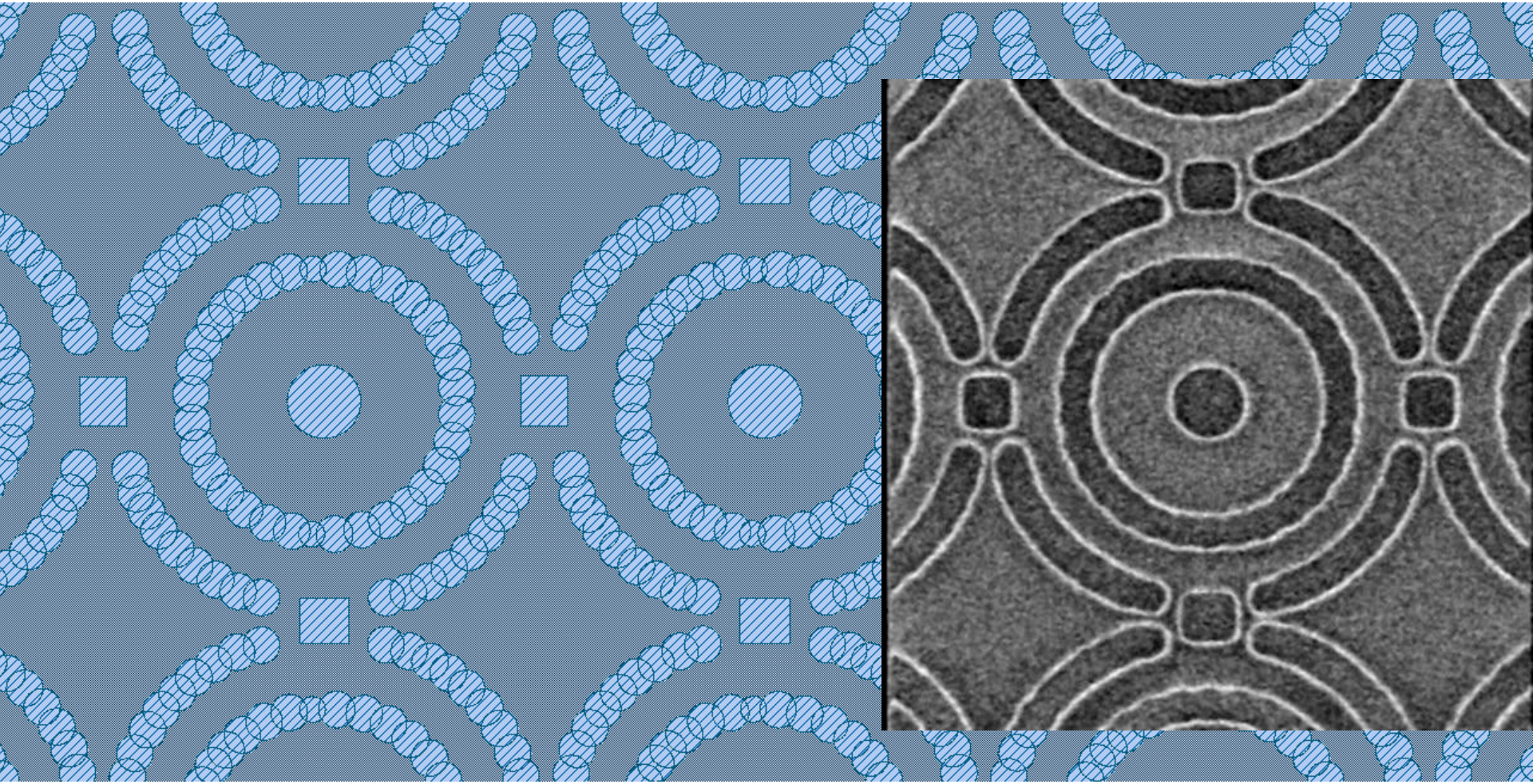
Continuous Range of Diameters from Discrete Aperture Sizes by Dose Modulation



JEOL JBX-3200MV allows each shot to be assigned one of 4095 dose values

Graphics and pictures courtesy JEOL, Ltd.

Sample Pattern Written with Circles



Test Case Courtesy of Samsung Electronics

Graphics and pictures courtesy JEOL, Ltd.

Machines Support Circles

- **To write continuously variable sizes of circles, two things are needed**
  - Discrete sizes of circular apertures
  - Dose modulation per shot to shoot the in-between sizes
- **Customer orders accepted for this capability at JEOL**

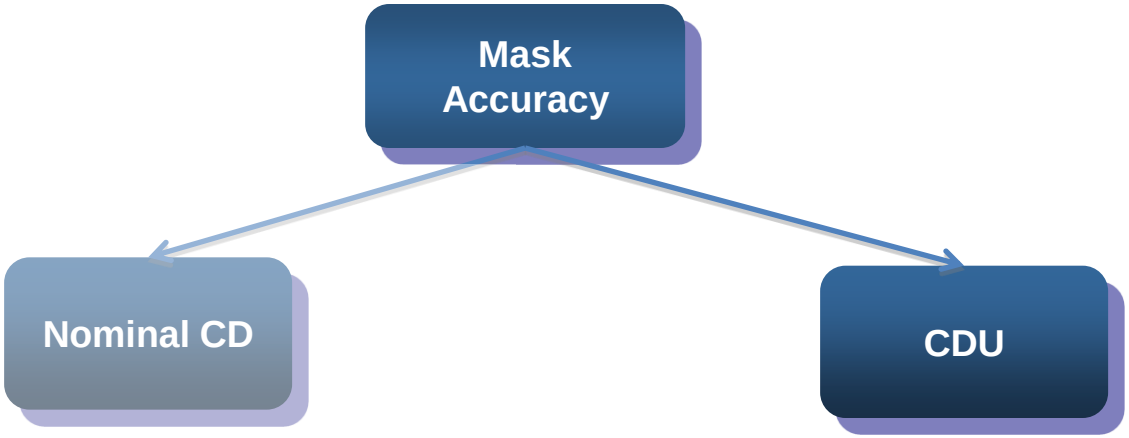
- **2012 focus: CDU improvement**
  - Substantial shot count savings and CDU improvement achievable
  - CD Split avoidance and Dose Margin improvement is expected in writing complex mask patterns

Insights into CD Uniformity Improvements

Ryan Pearman
Director of Modeling – D2S, Inc.
Robert Pack
D2S, Inc.

www.ebeam.org

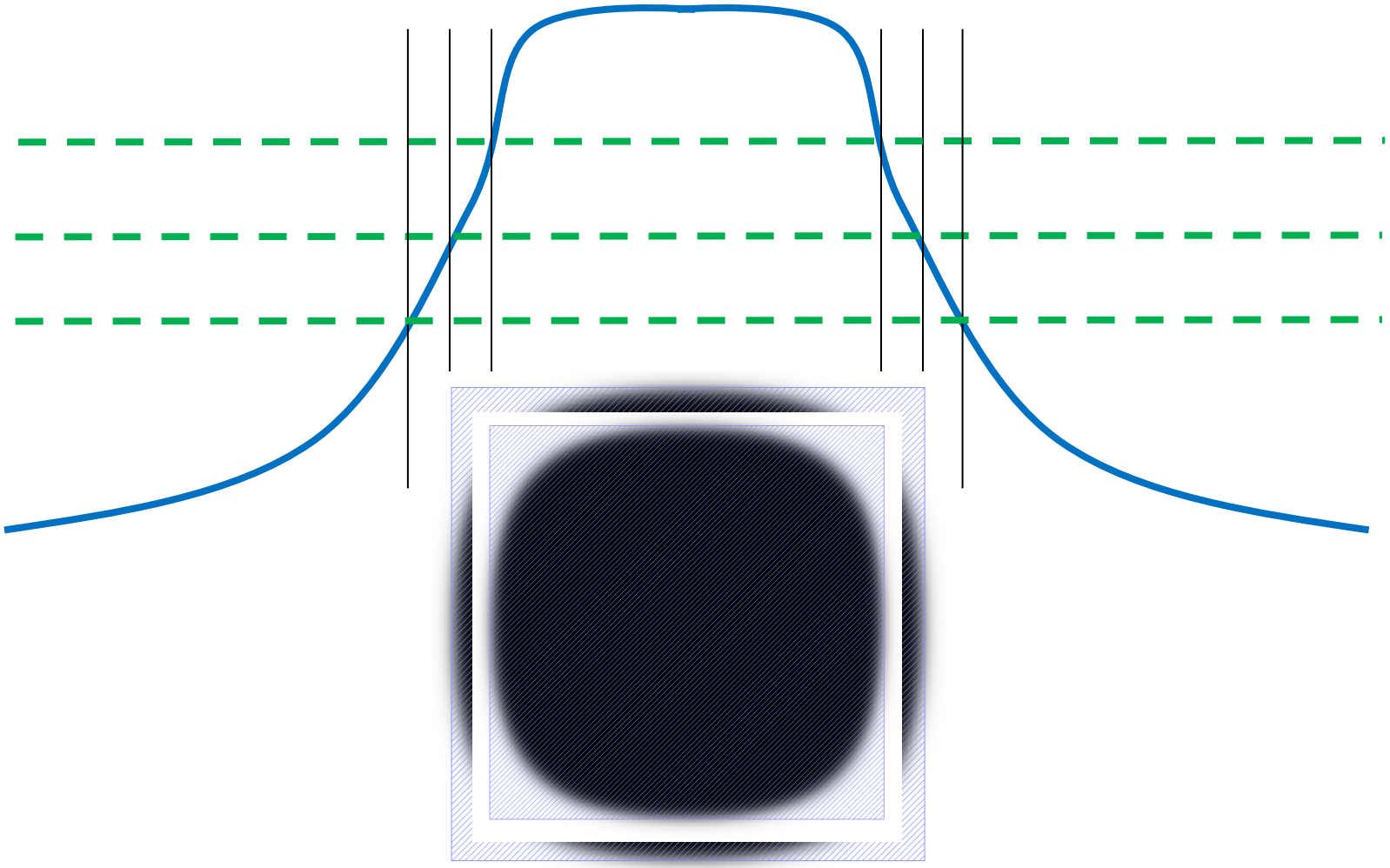
Critical Dimension Uniformity (CDU) on Mask



- CD Linearity
- Mask Process Modeling

- Dose Margin
- CD Split

Dose Margin is a Key to CDU

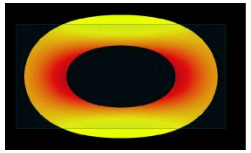


Dose Margin is Best with Circles

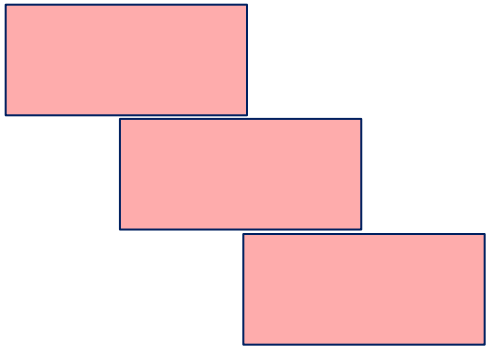
90 nm x 45 nm VSB Shot

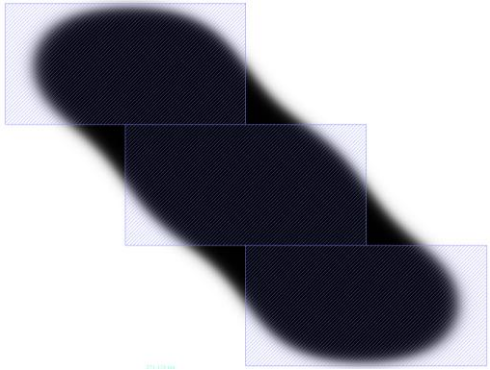
Simulated Image

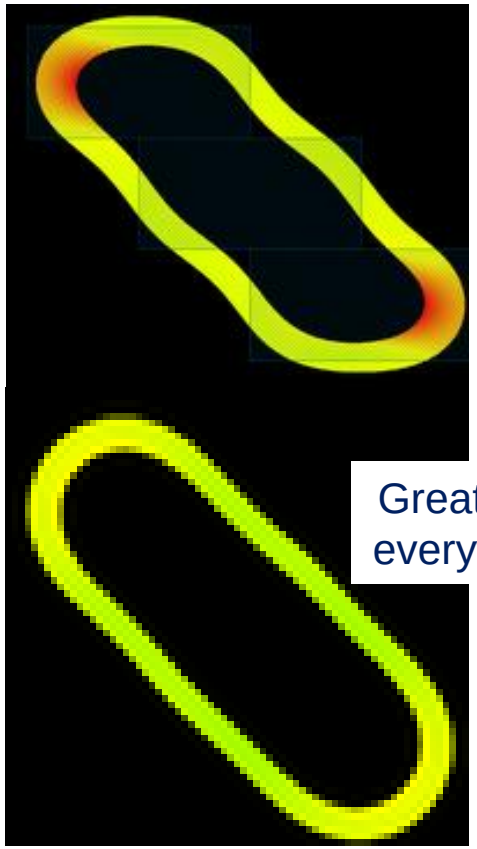
Dose Margin



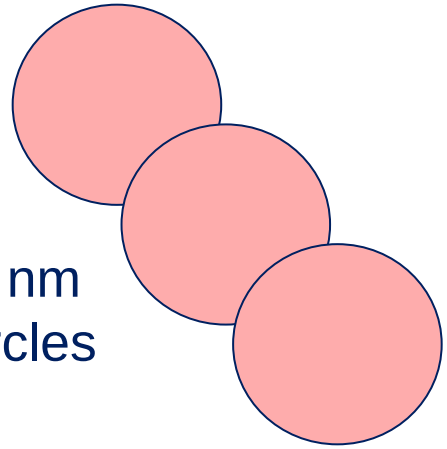
Bad DM
(red -- left and right)



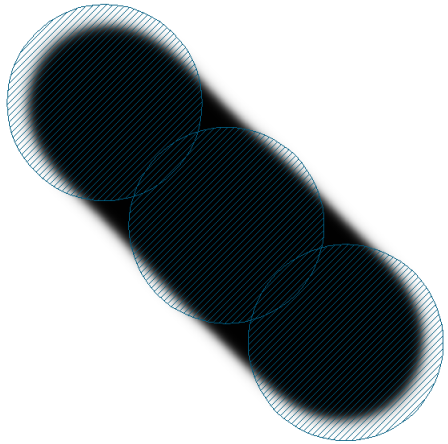




Great DM everywhere



72 nm Circles

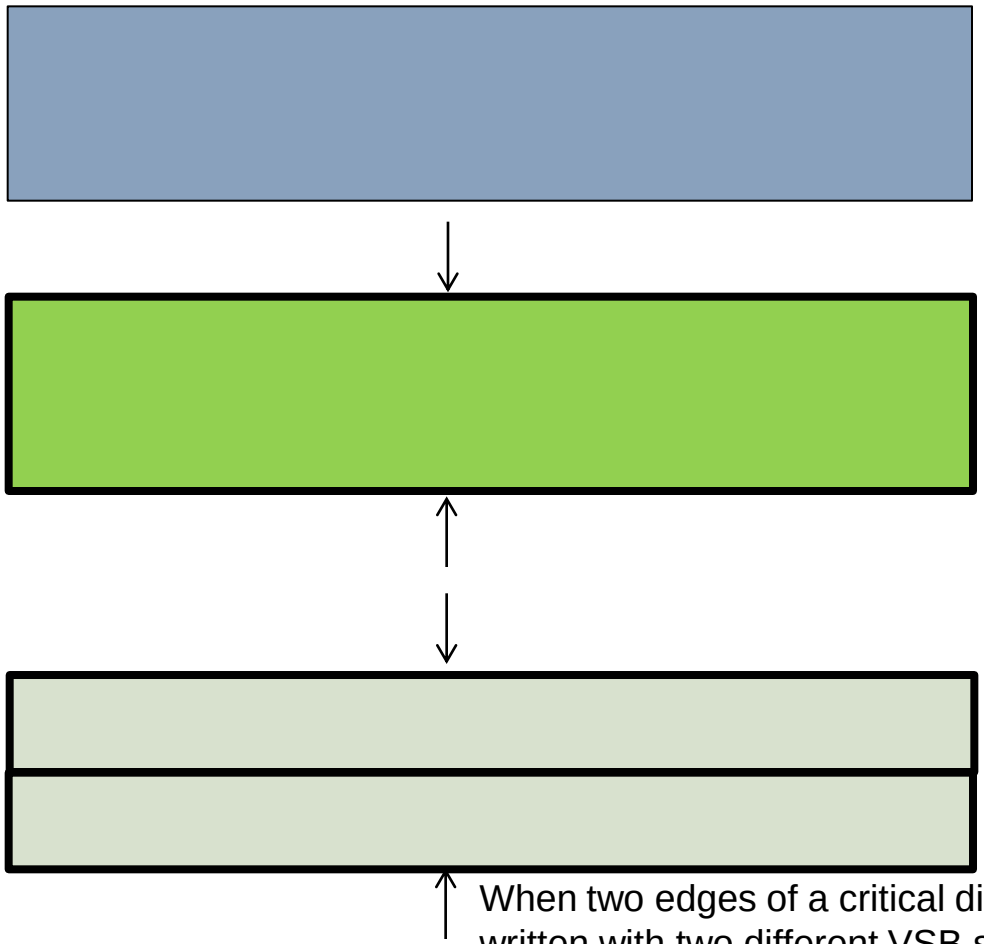


CD Split is Another Key to CDU

Desired
Mask Shape

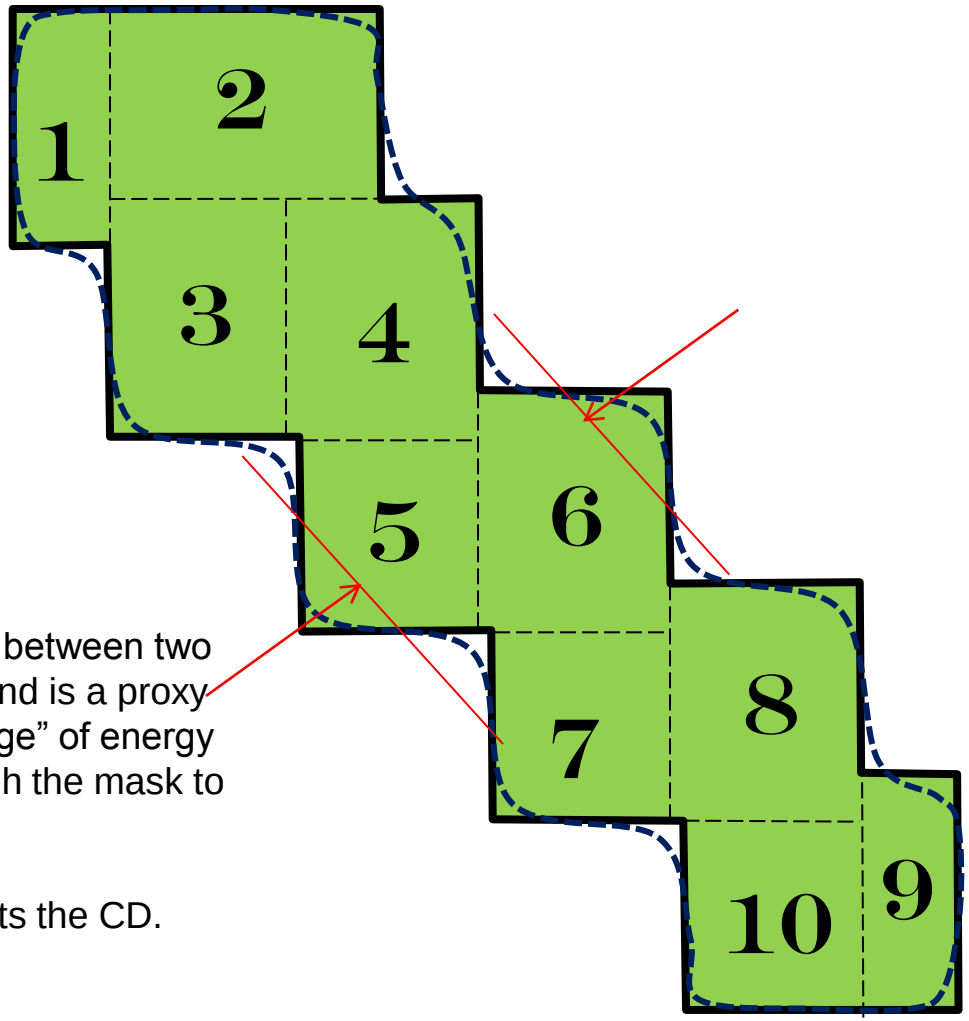
One Shot Solution
No CD Split

Two Shot Solution
With CD Split



When two edges of a critical dimension are written with two different VSB shots, positional error of the writer translates to worse CDU.

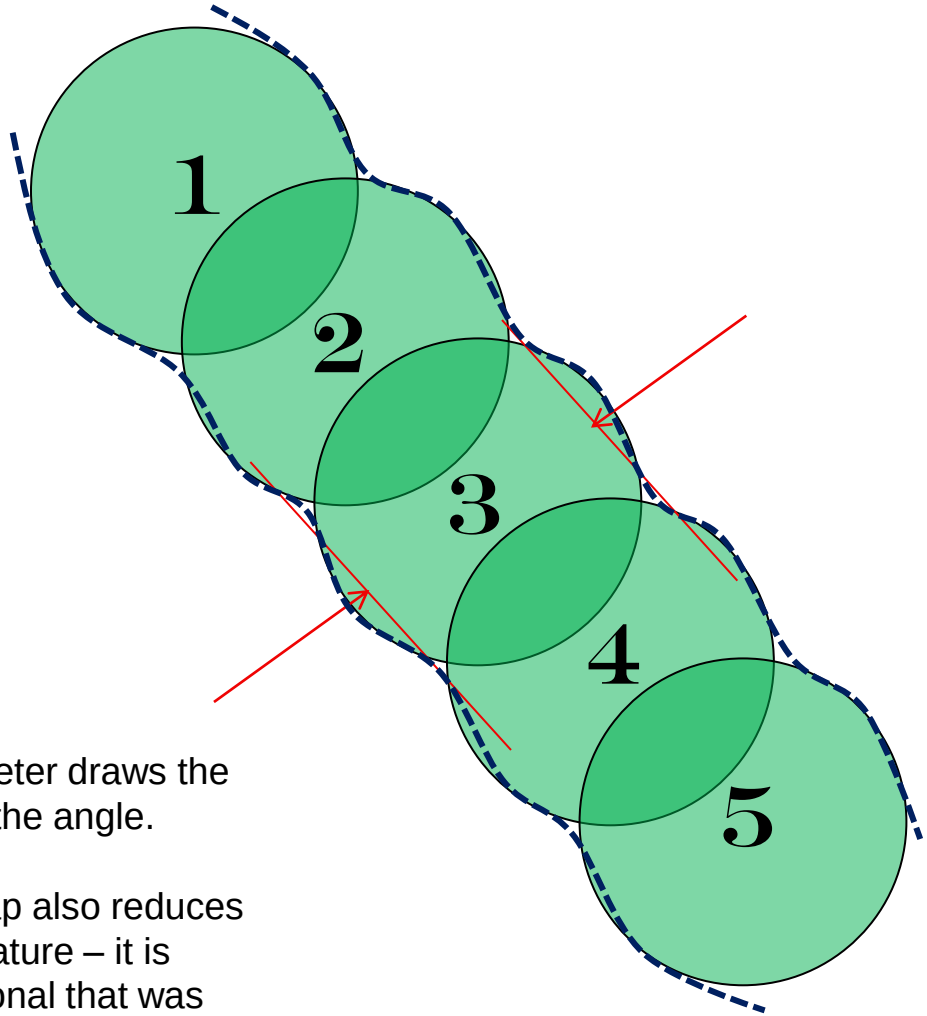
Complex ILT with non-orthogonal SRAFs



"CD" is measured between two wavy line edges and is a proxy for "running average" of energy transmitted through the mask to the wafer.

Shots 5 and 6 splits the CD.

Circles Avoid CD Split

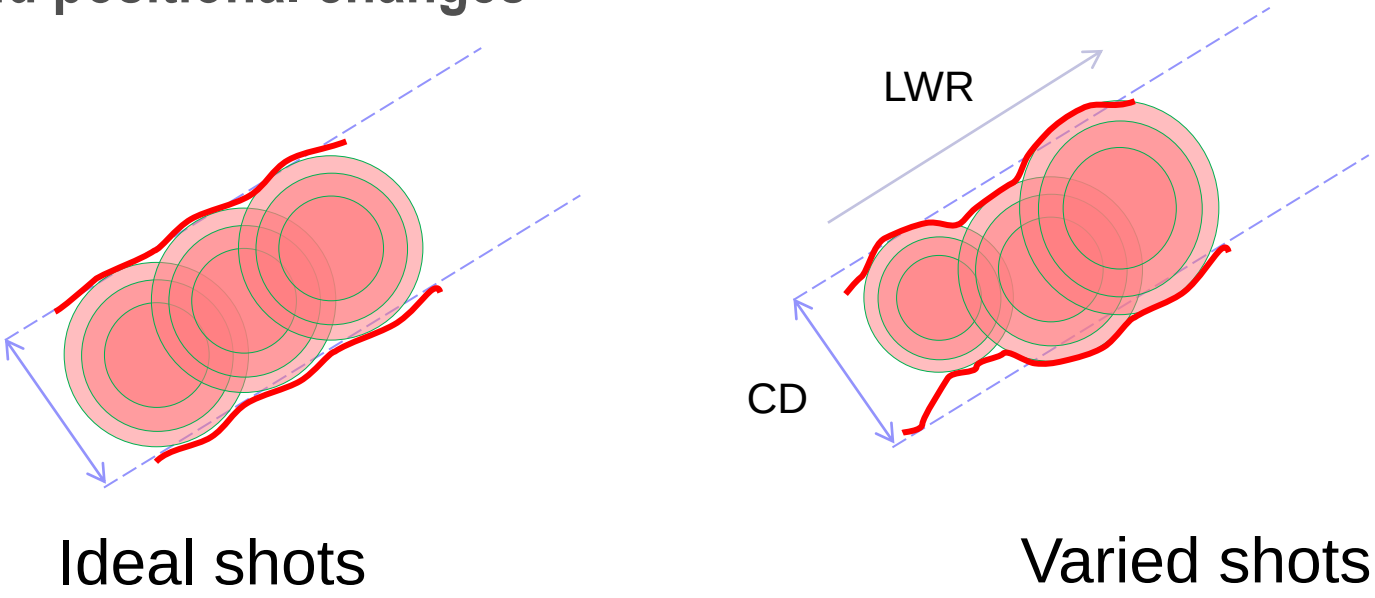


With circles, diameter draws the CD regardless of the angle.

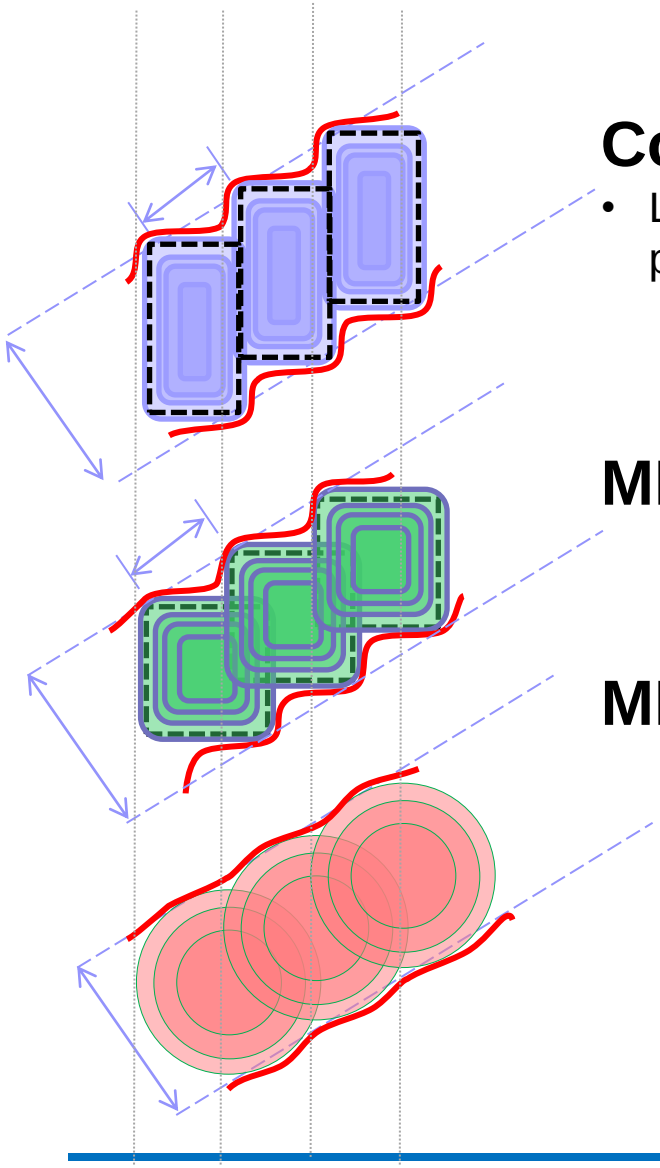
The natural overlap also reduces the LWR of the feature – it is closer to the diagonal that was desired.

D2S Simulation Experiment

- **Monte Carlo simulation of effect of shot and dose variability on many long 30 degree lines**
  - Vary dose (σ=5%)
  - Vary position (σ=1.5nm)
- **Objective: See the result in CD variation due to the combined dose and positional changes**



D2S Simulation Experiment



Conventional VSB

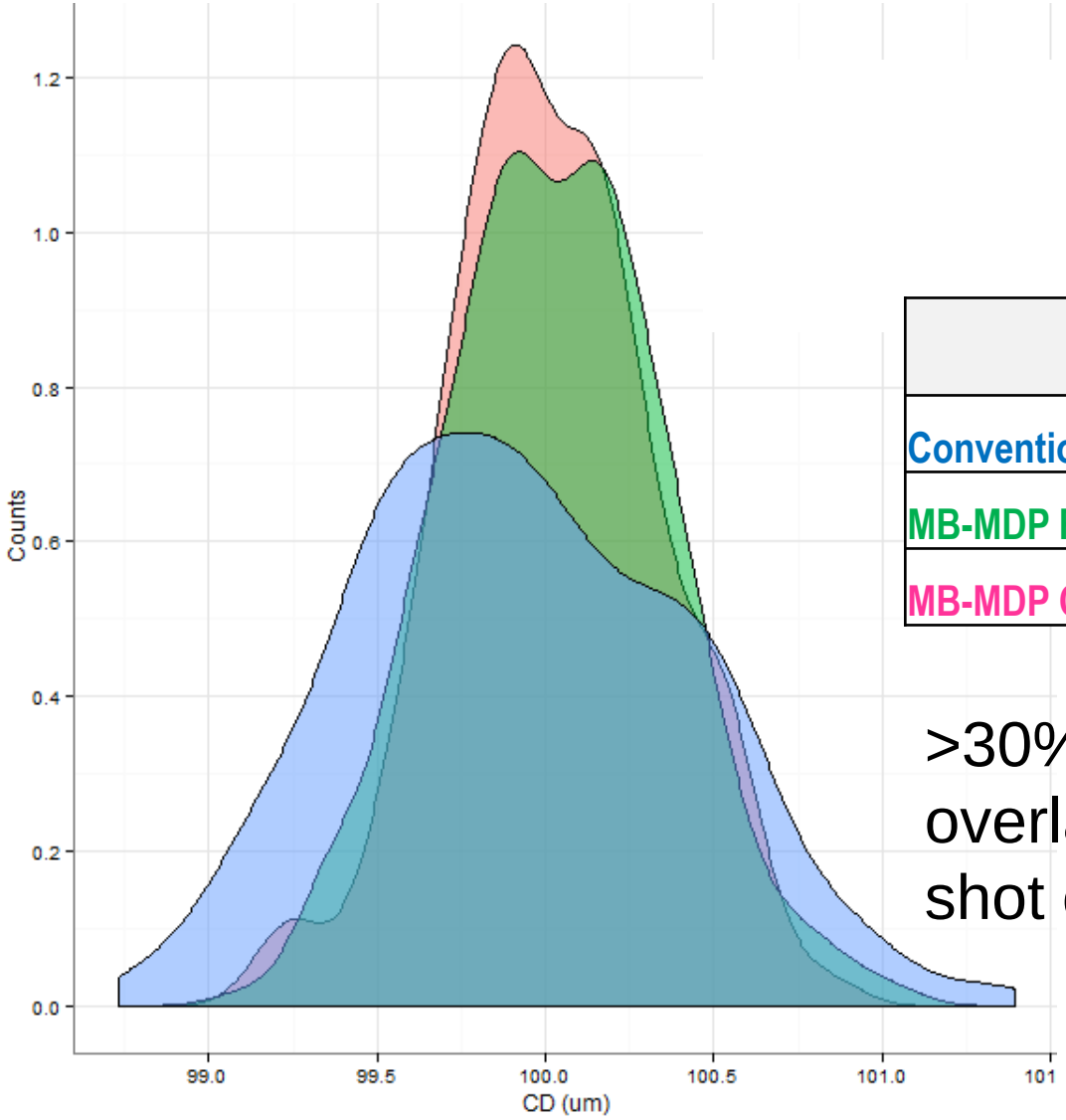
- Lower tolerance for shot placement error (CD Split)

MB-MDP Rectangles

MB-MDP Circles

- High tolerance for shot placement error
- Potentially higher fidelity, CD Uniformity
- Potentially lower cost if shot width can be increased for same fidelity

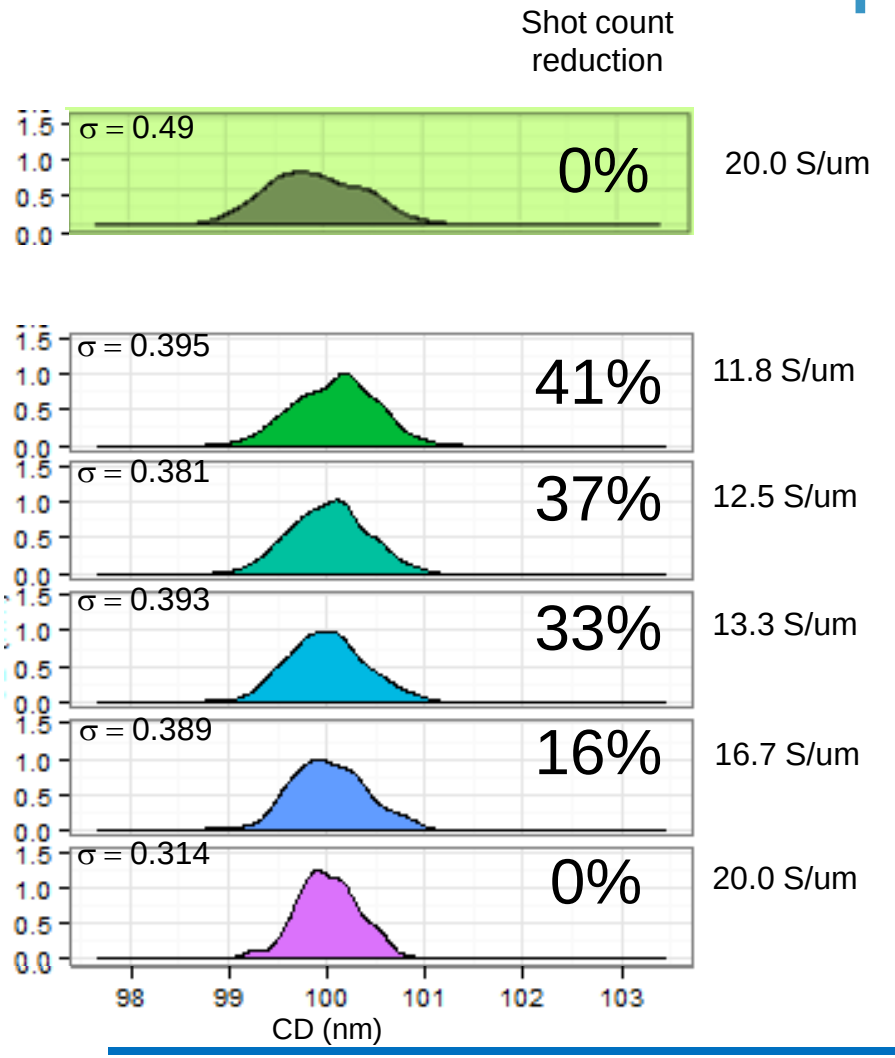
MB-MDP Improves Mask CDU



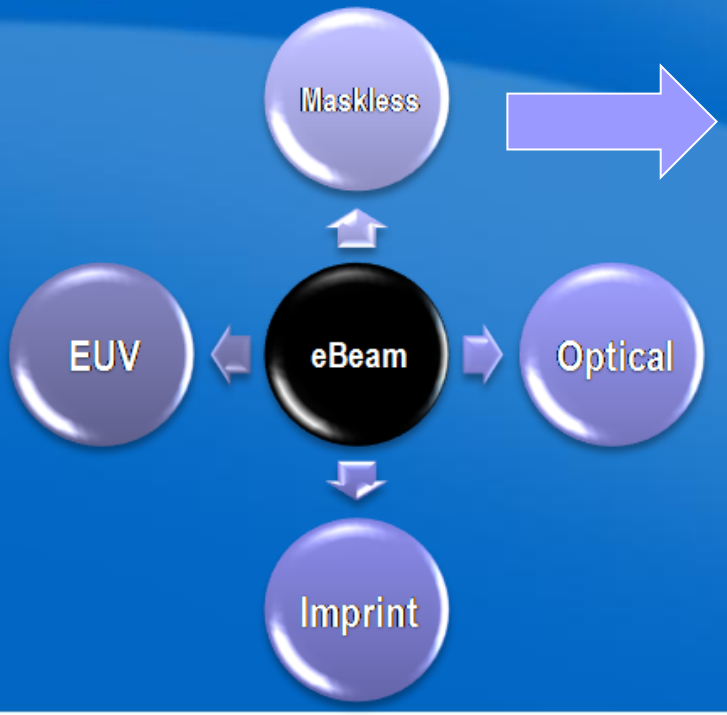
	<CD> Range	<CD> Sigma	<LWR>
Conventional	2.66	0.49	4.13
MB-MDP Rectangle	1.95	0.33	2.83
MB-MDP Circle	1.72	0.32	2.70

>30% CDU improvement for overlapping shots with the same shot count

MB-MDP with Circles
Reduces Shot Count and Improves Mask CDU



eBeam Initiative Member Collaboration: Complementary eBeam Lithography (CEBL)



- 1x writing of wafers
- No decorations or SRAFs
- >10 WPH required vs. hours/mask

- Great depth of focus
- Stitching accuracy more difficult

Complementary e-Beam Lithography

Sub-20nm Collaborative Results

Michael Smayling, Jérôme Belledent, Laurent Pain

Topics

- CMOS Technology Scaling Below 20nm
- Design and Lithography Solutions
- Optical Results
- Complementary e-Beam Lithography
- eBeam Initiative Project

CMOS Technology Scaling

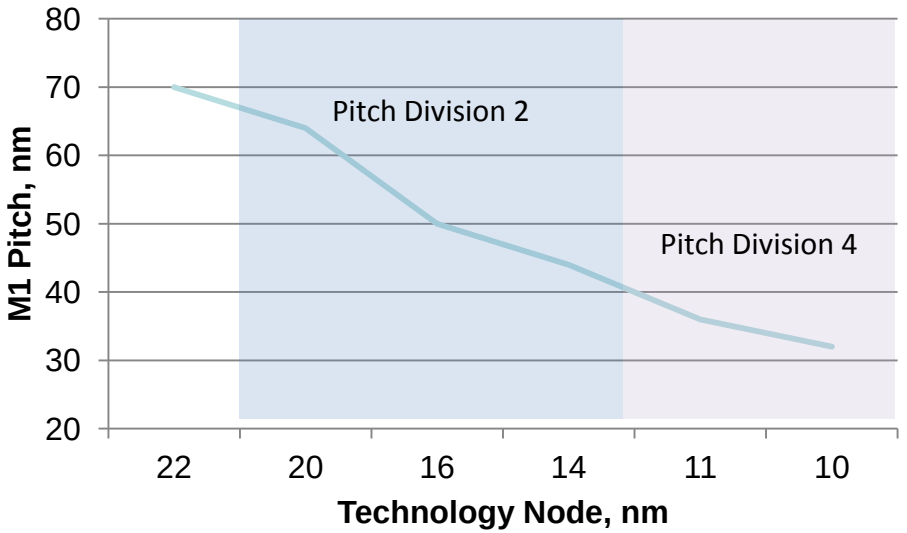
Node:	22	20	16	14	11	10
X-Pitch	90	82	64	58	46	42
Y-Pitch	70	62	50	44	36	32
Gate Cut (X – Y)	90 x 35	82 x 31	64 x 25	58 x 22	46 x 18	42 x 16
M1 Cut (X – Y)	45 x 70	41 x 62	32 x 50	29 x 44	23 x 36	21 x 32

- Gate lines are vertical, so they use the X-pitch.
- Metal-1 lines are horizontal, so they use the Y-pitch
- Cuts for critical layers of Gate and Metal-1 are listed

- These are estimates based on experience, not specific wafer fab information

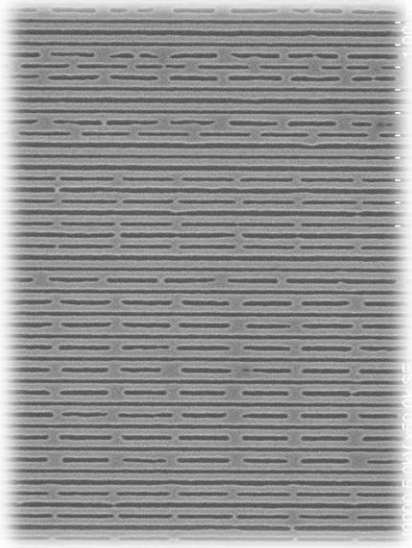
Design and Lithography solutions

- λ/NA = 143nm is the limit of optical systems today
- Tela's patented and patent pending 1D gridded design style allows splitting the circuit pattern into lines and cuts
- For pitches < 80nm, pitch division is needed for lines
- The cuts need single to multiple optical exposures or CEBL



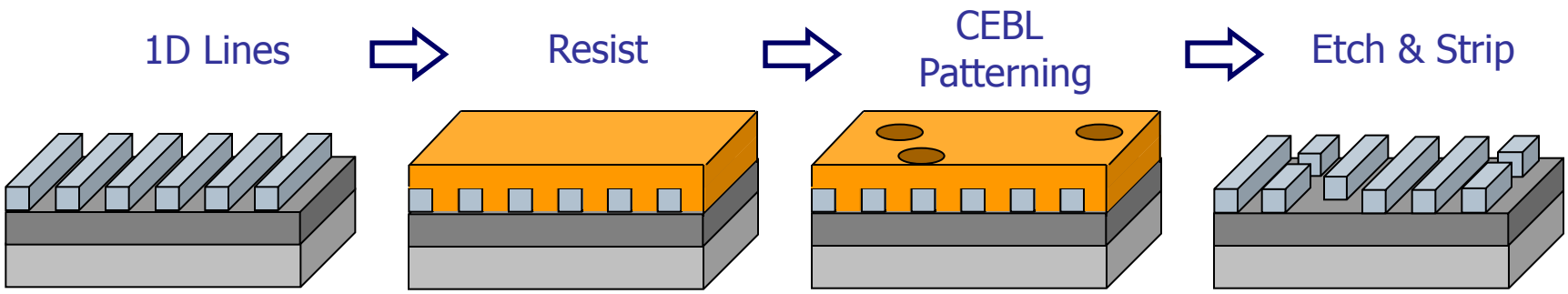
Optical Results to 16nm

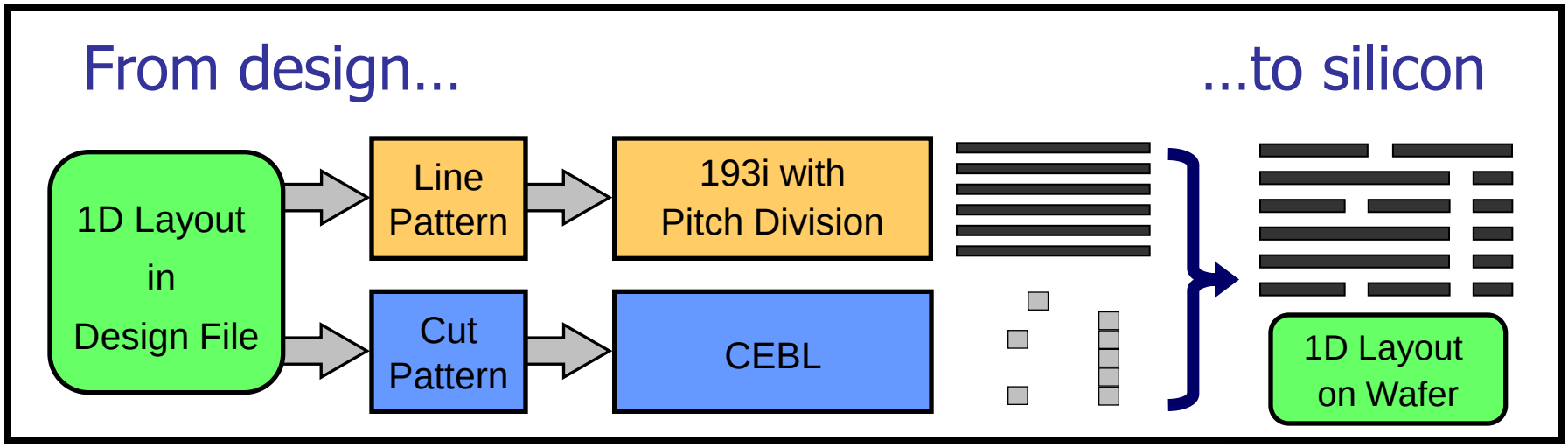
- Tela's patented and patent pending 1D gridded design style
- Canon + Sequoia simplified OPC
- TEL SDP and optical cut processing
- 8326-39 on Thursday morning will have more details



16nm Metal-1

Complementary e-Beam Lithography





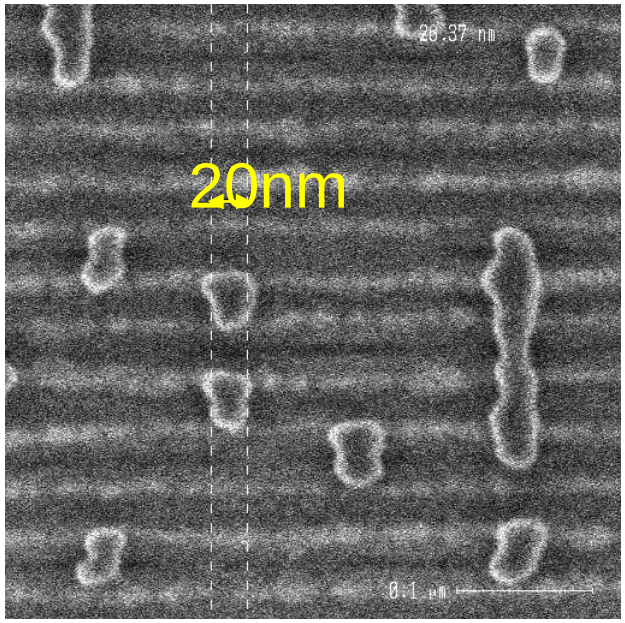
eBeam Initiative Project

- Following SPIE Advanced Lithography in 2011, there was an interest amongst several members to investigate the limits to CEBL with currently available equipment and processes
- The eBeam Initiative facilitator brought together several potential collaborators
- After several exploratory meetings, we converged on a project involving CEA-Leti and Tela Innovations
- In a truly collaborative spirit, with very open discussion and debate, we eventually planned and carried out the project to be presented today
- Please note that the CEA-Leti team really did the “heavy lifting” to make this a success!!

Our CEBL Results to 11nm Node

- Tela's patented and patent pending 1D gridded design style
- Joint testchip
- CEA Leti data processing and wafer processing
- Exposure on Vistec system

- 8323-14 on Tuesday afternoon (right after our luncheon)



11nm Metal-1

Summary

- CMOS scaling can continue with optical lithography alone through 16nm
- e-Beam will complement optical lithography below 16nm
- Tela's patented and patent pending 1D design style supports the decomposition into lines and cuts needed for both optical lithography and CEBL
- This "proof point" shows the value of collaboration and is just the beginning of the path to production

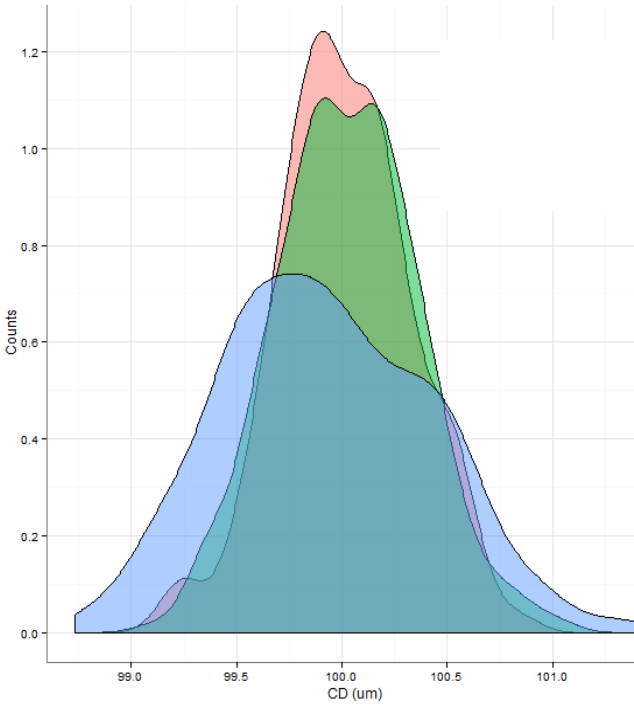
Acknowledgements

- Special thanks to the CEA-Leti team:
  - Jérôme Belledent (here today) and Laurent Pain
  - J. Pradelles, P. Pimenta-Barros, S. Barnola, L. Mage, B. Icard, C. Lapeyre, S. Soulan
  - The wafer fab processing team

- Visit us on the web at
  - www-leti.cea.fr/en
  - www.tela-inc.com

Thank You to Members for Your Contributions

- Membership in the eBeam Initiative grows to 42
- eBeam technologies improve mask CDU
- Machines support circular eBeam shots for improved CDU
- eBeam maskless technology will complement optical lithography below16nm
- SPIE papers presented by eBeam Initiative members
  - Advantest, CEA-Leti, e-Shuttle, EQUIcon, Fujitsu, Fraunhofer-CNT, Multibeam, Synopsys, Tela Innovations, Vistec

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